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Development of couplant-free point-contact ultrasonic probe for concrete measurement

コンクリート計測のための縦波点接触カプラントフリー探触子の開発

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1. Introduction

For ultrasonic nondestructive inspection of concrete structures with large surface irregularities, flaw detection is practically difficult since the dedicated acoustic couplant with high viscosity is required. Moreover, there is an essential problem that couplant remains on the surface of the concrete. On the other hand, impact echo method[1)] using elastic waves and phased array system using 64 shear wave point contact probes with 50 kHz[2,3)] have been proposed as the methods that do not require couplant. However, since these are measurements using low frequencies, they are not suitable for precise flaw detection in concrete.

Therefore, we have developed longitudinal wave point contact probes of about several hundred kHz with the goal of the couplant-free measurement system which can various concrete parts[4)]. However, the excitation frequency and amplitude have been changed greatly by the piezoelectric element size in designing the contact area reduction for realizing couplant-free measurement. In this study, we systematically clarify these behaviors by piezoelectric coupled finite element method (FEM) analysis. We prototyped probes based on the analysis results, and evaluated its effectiveness by the experiments using an ultrahigh strength fiber reinforced concrete (UFC) blocks.

2. FEM analysis of frequency constant

To systematically clarify the relationship between the element size and the excitation frequency and amplitude, we define the shape of vertical effect piezoelectric vibrator with square cross section as

$$\mathrm{AR} = t/w \cdots (1)$$

where, t and w are the thickness and width, respectively.

The responses of soft-type PZT ceramics vibrators (Fuji Ceramics, C9) on electric impedance and top surface displacement were analyzed with AR in the range of 0.1 to 3.0 to spike signal (-1.0 kV) **[Fig.1]** (Weidlinger Associates, PZFlex™).

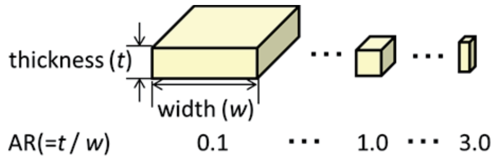

Fig. 1 Schematic diagram of analysis model.

Figure 2 shows typical results. Fig. 2(a) shows the impedance spectra, normalized by the frequency f_1 and impedance Z_{f_1} at the fundamental resonance of a rod. As AR decreases i.e. approaches a plate, higher order modes f_2, f_3 become clear in addition to f_1. Fig. 2(b) shows the surface displacement waveforms corresponding to Fig. 2(a). Damped vibrations with single period are excited in AR of 2.0 and 1.0. However, a superposition of higher order vibration is observed in AR of 0.2.

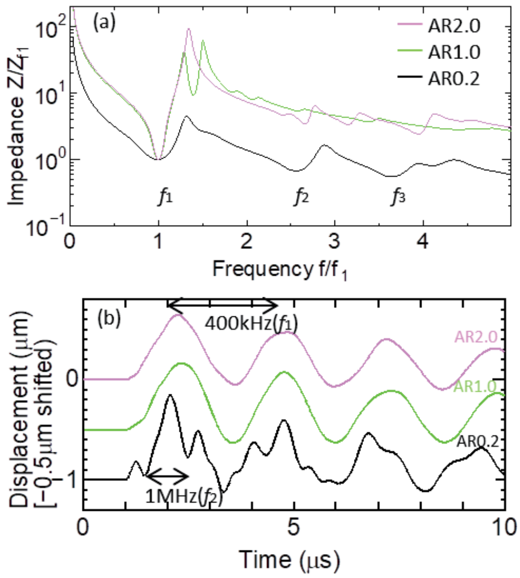

Fig. 2 Typical responses. (a) Impedance spectra. (b) Displacement waveforms.

Figure 3 shows the AR dependence of frequency constant N and maximum displacement $d_{\max}$. N decreases monotonically as AR decreases. When AR <1, $d_{\max}$ increases up to about 1.3 times. This is due to the superposition of higher order vibration on fundamental mode.

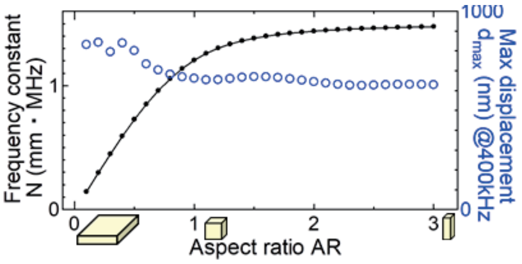

Fig. 3 AR dependence of frequency constant N and maximum displacement d_{max}.

3. Fabrication of point contact probes

The vibrators with the fundamental frequency of 400 kHz were fabricated based on Fig. 3. **Figure 4** shows measured impedance spectra. w were 2.0, 3.0, and 4.2 mm for AR of 1.6, 1.0, and 0.2, respectively. The AR dependence of the spectra was similar to Fig. 1(a). The fundamental frequencies were almost 400 kHz. **Figure 5** shows schematic diagram and picture of a prototype probe. Al_2O_3 ceramics hemispheres (3mm in diameter) were used for the tip.

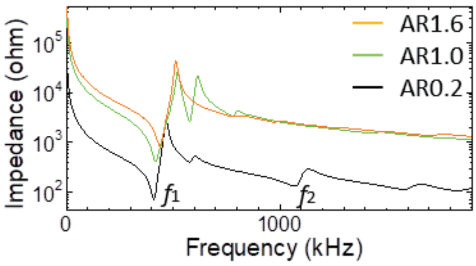

Fig. 4 Impedance spectra of vibrators.

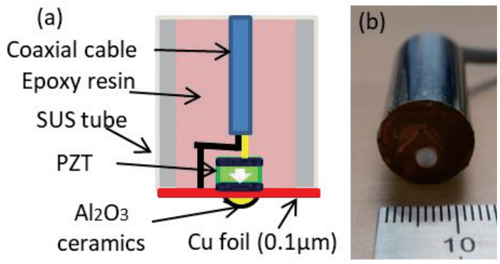

Fig. 5 Prototyped probe (a)Schematics of cross section. (b) picture.

4. Evaluation

Figure 6 shows a schematic diagram of an experimental configuration. The sample is UFC block (Taiheiyo Cement Corporation) with the thickness and width of 200 mm and the length of 800mm. The probes were excited with -490 V spike signal at open circuit (ISL, FPRIa), and the transmitted waves were measured with a laser vibrometer (Polytec, OVF-2570).

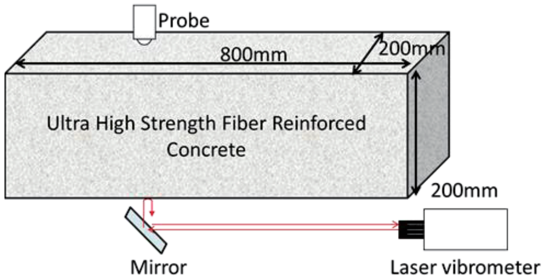

Fig. 6 Experimental configuration.

Figure 7 shows the measurement results. Longitudinal transmitted waves were measured at 43 µs in all cases, resulting in the longitudinal sound velocity was about 4600 m/s. The probe of AR1.6 had ringing of about 330 kHz. The ringing decreased as AR decreases, and the signal-to-noise ratio improved. This is considered to be an effect where higher order modes are excited simultaneously.

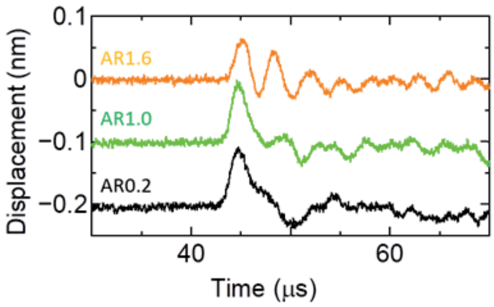

Fig. 7 Transmission waveforms through 200 mm thickness of UFC block.

5. Conclusion

A design method of piezoelectric elements with intermediate shapes between the rod and the plate was developed. The usefulness was verified in fabrication of point contact probes of several hundred kHz. In the future, we aim to realize the transmission and reception between developed probes.

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References

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